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WEATHER HAZARD SIMULATION IN THE MODANE WIND TUNNELS

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16. Abstract

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WEATHER HAZARD SIMULATION IN THE MODANE WIND TUNNELS

Guy Fasso, Guy Leclere and Francois Charpin
Office National d'Etudes et de Recherches Aerospatiales (ONERA)
Modane-Avrieux Center

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Summary

Specially designed wind tunnel setups make it possible to simulate various weather hazards, in an imperfect but systematic manner. The paper briefly describes the systems installed in the Modane wind tunnels:

-- rain tests, at large scale and moderate speed, in the S1-MA, or at high speed on a smaller scale in the S3-MA;

-- icing tests, at full or reduced scale, in the S1-MA, with aircraft parts, full aircraft models and helicopter rotors;

-- gust simulator, currently in the design phase.

The main results obtained in the last ten years for rain and icing are reported.

Introduction

The first stage in the study of an aircraft consists in defining its behavior and performance in a standard atmosphere, i.e. for ideal good weather. A second stage consists in evaluating the effects of bad weather on the behavior of the equipment.

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* Numbers in the margin indicate pagination in the foreign text.

Wind-tunnel simulation of these conditions presents different problems from classic aerodynamic tests performed in a permanent and homogeneous flow.

Weather hazards are essentially inhomogeneities: non-uniformity of air speed (gusts or turbulence), and a two- or ~~three-phase aerosol environment, instead of a one-phase~~ gaseous mixture (clear air). The dispersed phase is generally made up of water in drops, droplets, crystals or spherules (ice); but it can also contain dust, sand, or even kerosene (in the event of in-flight refueling).

Wind-tunnel simulation of this environment is of obvious interest, even if it is only partial and imperfect. The tests can be performed at an early stage of the development of the design, before it has been frozen or the prototype has been authorized to confront hazardous flight conditions. The conditions of a wind-tunnel test are well defined, variable and reproducible at will; the possibilities for observation, measurement and recording are far greater than in flight. Finally, and above all, it is possible to study extreme conditions without danger.

But these tests require infinitely varied natural conditions to be defined and standardized at a low number to make them reproducible in a wind tunnel. Moreover, the laws of aerodynamic similitude must be complemented with conditions relative to aerosol mechanics and collection phenomena. The combination of conditions thus created generally cannot be realized intact; one must thus be content with a limited similitude, assuring at best a reproduction of the essential phenomena under consideration without pretending to any quantitative precision comparable to that in aerodynamic tests.

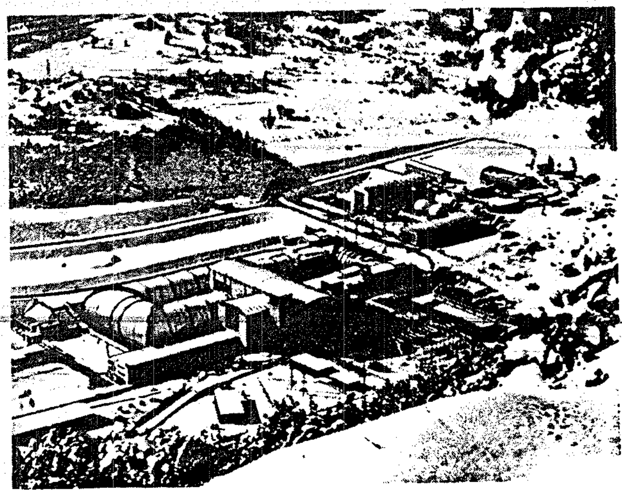

Fig. 1.

The Modane-Avrieux Center in winter.

At the Modane Test Center (Fig. 1), ONERA developed possibilities for rain simulation, on the one hand at low and medium speed in the large S1 wind tunnel for windshield visibility studies [1], and on the other hand at higher speed (up to Mach 0.83) in the S3 gust wind tunnel, to reproduce the erosion effects due to rain [2]. The winter rigors of Modane additionally allow icing tests in the S1. Finally, a gust simulation system is being studied for this same wind tunnel.

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The essential features of these different possibilities will be reviewed quickly; most have already been the subject of previous publications.

Rain Simulation

Natural rain can be characterized by its liquid water content in grams per m^3, and by the mean drop diameter in mm. There is a certain correlation between these two parameters and with the standard meteorological datum of rain intensity at ground level in mm/hr (Fig. 2). For our tests, we defined three typical rains (symbols: □), very close to those chosen

by the U.S. Air Force for the same purpose: moderate, heavy and violent, with water contents of 0.3, 0.9 and 2.2 g/m^3 for respective diameters of 1, .5 [sic] and 2.2 mm.

To simulate these conditions, water was injected into the air stream at a speed very close to that of the stream, by calibrated spray nozzles moving in a two-dimensional sweeping motion, assuring a correct distribution and water content at

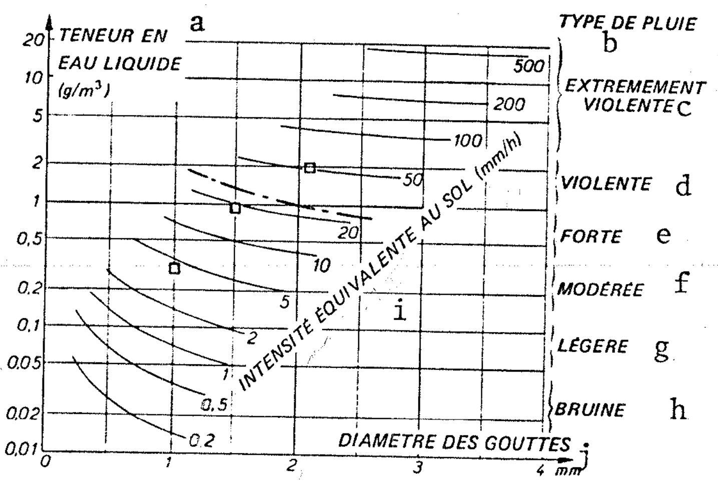

Fig. 2. Statistical characteristics of rain: rain types simulated in the wind tunnel.

Key:
a. liquid water content
b. rain type
c. extremely violent
d. violent
e. heavy
f. moderate
g. light
h. drizzle
i. equivalent ground intensity (mm/hr)
j. drop diameter

the level of the model. For the study of visibility through a real windshield mounted on a full-scale fuselage model, the sprayer system uses 5 or 7 nozzles with a conical spiral motion (Fig. 3). The construction, controls and calibration of this system are described in reference [1].

The test pilot, installed in his cockpit, evaluates the visibility of painted marks or more distant light sources, as well as the manner in which the windshield is clouded, at various speeds (up to 140 m/sec) and for various angles of

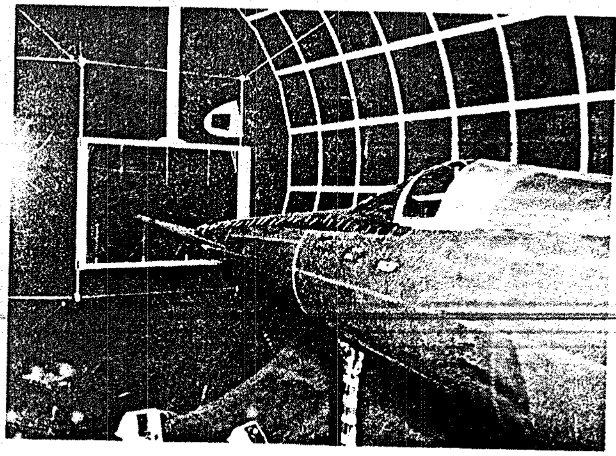

Fig. 3.

Rain tests in the S1-MA wind tunnel.

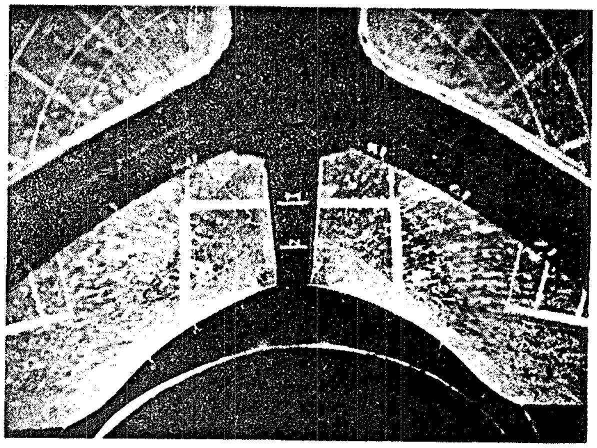

Fig. 4.

View through the windshield. Violent rain, low angle of incidence, zero side-slip, low speed.

incidence and side-slip (Fig. 4). His observations, noted in code, are cross-checked by filmed shots with the camera in the same position as the pilot's head. Although the simulation is imperfect, since the sweeping motion is periodic instead of random, the obtained results are significant and representative of real flight conditions.

To simulate the erosion caused by rain, which can be seen from Mach 0.5 upwards and increases very rapidly with speed, the principle for the solution as well as the types of rain to be simulated are the same, but the practical construction

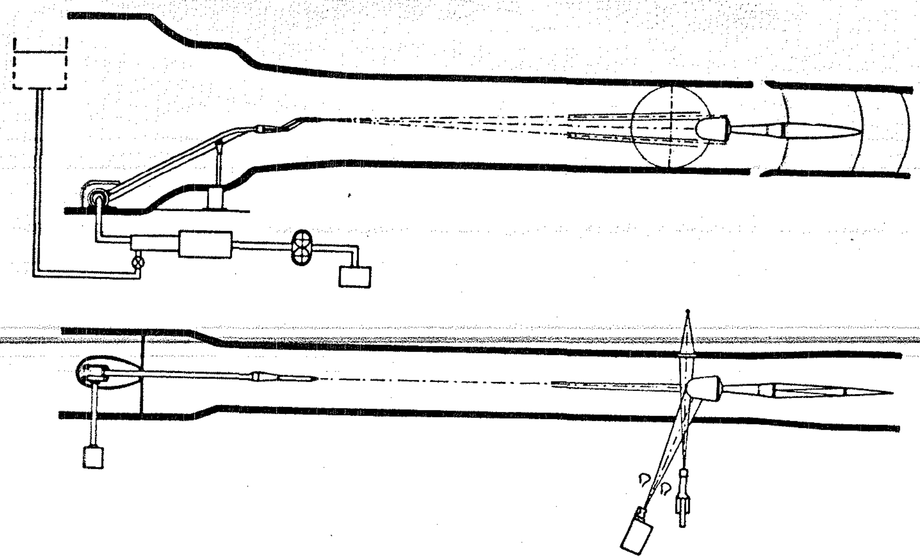

Fig. 5. Rain simulation equipment in the trans-sonic stream of S3-MA

is much more difficult (Fig. 5). The injection pressure must reach several hundred bars, the transit distance of the drops is shorter, and the decreased dispersion leads to much higher liquid water contents than in natural rain. But the test structures -- radomes, irdomes or leading-edge components -- can easily be accommodated in wind tunnel S3, which thus constitutes an accelerated test facility. The erosion phenomena are reproduced in a realistic manner, with an acceleration factor of 10 to 100, depending on the sweeping motion chosen (in 1 or 2 dimensions).

As an example, Fig. 6 shows the death of a radome (of obsolete design) at Mach 0.6, which took 22 seconds in the wind tunnel, corresponding to 30 minutes of flight; the equivalence is based on the ratio of liquid water contents for a "heavy" rain (drops from 1.3 to 1.5 mm). In this case, it was possible to compare the results to those in flight, and the confirmation was satisfactory.

In spite of its limitations, this type of test offers

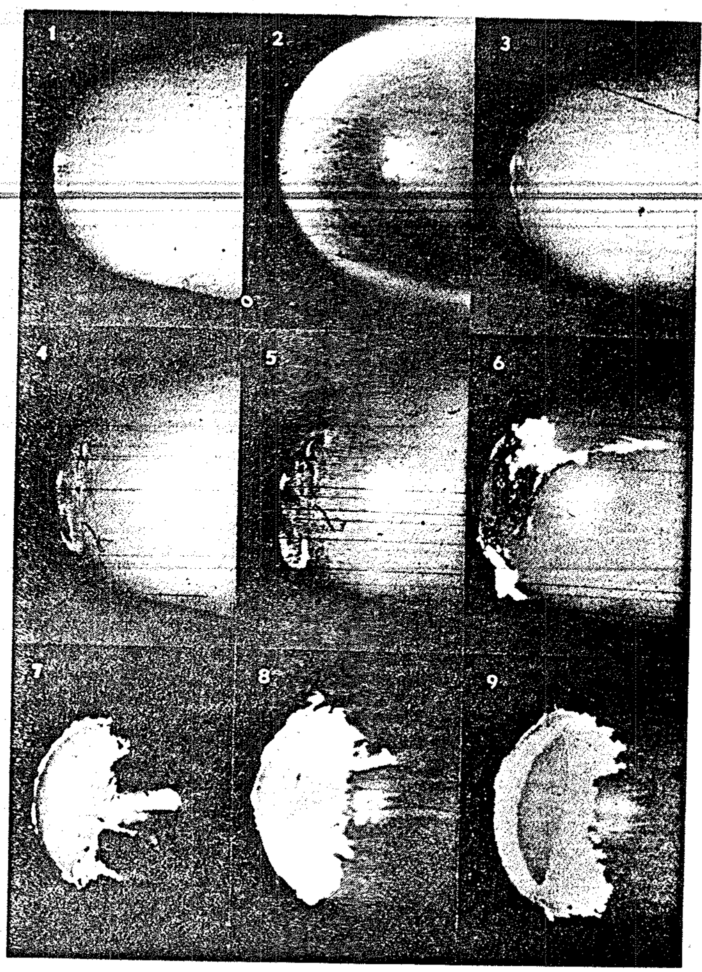

Fig. 6. Sequential views of a radome during erosion.
M = 0.63, heavy rain.

t = real wind-tunnel time

t_{ev} = equivalent flight time

1 - t = -1 sec. before rain
2 - t = 0 start of rain

[s = sec below]

3 – t = 4,9 s, t_{ev} = 400 s
4 – t = 6,3 s, t_{ev} = 520 s
5 – t = 6,8 s, t_{ev} = 560 s
6 – t = 8,1 s, t_{ev} = 670 s
7 – t = 10,4 s, t_{ev} = 850 s
8 – t = 13,7 s, t_{ev} = 1 130 s
9 – t = 21,9 s, t_{ev} = 1 800 s

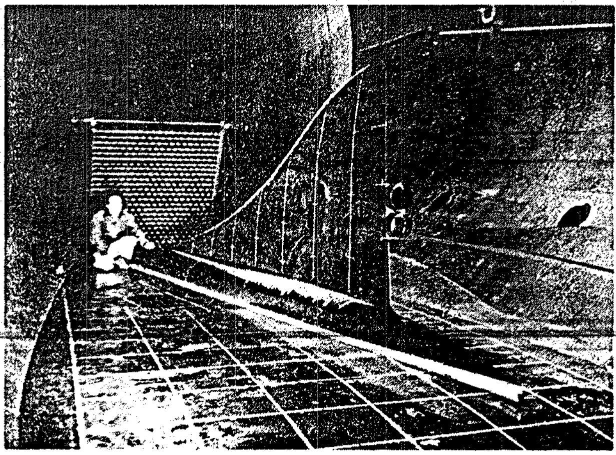

Fig. 7. Pulverization grill for icing simulation in the S1-MA.

offers specific advantages over the other ground test methods; it is clearly less expensive than rocket-propelled trolleys on rails, and allows detailed observation of phenomena filmed at high speed barely a meter from the model. In a few gusts it is possible to simulate the cumulative erosion of several hours of flight in rain, which would require hundreds of rail shots. However, the turning arm, which is certainly less expensive, can only test samples of materials or coverings, but not complete structures. Finally, further development is possible in the transsonic range up to Mach 1.1 or 1.2, and possibly in the supersonic range up to Mach 2.

Icing

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In the large wind tunnel, thanks to cooling via air exchange with the outside, the temperature in winter often drops below -5°C, -10°C or even -15°C. This allows icing tests using a cloud of supercooled water droplets upstream of the models (Fig. 7). The characteristics of these clouds are well defined in the standards of the different Atlantic countries (cf. Appendix 1). Typically, the mean volume diameter is 20 microns, the liquid water content is 0.6 to 0.8 g/m^3 for large-size stratified clouds ("maximum continuous" icing). In the "maximum intermittent" icing conditions found in

cumuliform clouds, it reaches 2.2 to 2.5 g/m^3 for a typical extent of 5 km. These conditions, particularly the required alternation between them, were reproducible in the case of tests on full-scale aircraft components (wings, stabilizers, radomes) by the same means used in flight, particularly in Great Britain: Pulverization grills with Napier sprayers.

But in certain cases, particularly for the Concorde, reduced-scale testing was a necessity. Laws of limited similitude were established for these cases by researchers from Douglas, Lockheed, NAE and later BAC and ONERA [3]. They consider neither the Mach number nor the Reynolds number, but do assure the similitude of the collection of droplets and, in an approximate manner, similitude of the thermodynamic exchanges governing the formation of ice deposits. These laws generally lead to finer fogs, lower speeds and water contents that are higher at the reduced scale than at full scale. ONERA studied, constructed and calibrated a new pulverization grill in keeping with these requirements for the case of scale models at 1/6 (Concorde) and 1/12 (Airbus)(Fig. 8). Because of the approximations, simplifications and uncertainties of this technique, its validity was verified experimentally by applying it in the wind tunnel to controls at full and reduced scale.

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The result is deplorable if one does not apply the rules: i.e., if one ices the 150 mm cylinder (Fig. 9) and the 25 mm one (Fig. 9) in the same way. Thanks to photography, the comparison is direct.

On the other hand, if the rules are applied, the ice deposits have a remarkable similitude in geometry; only their appearance is a little different. The same good results were obtained with other control forms: delta wings with an acute edge, and classic profiles at the scales of 1/6 and 1/12 (Fig.10).

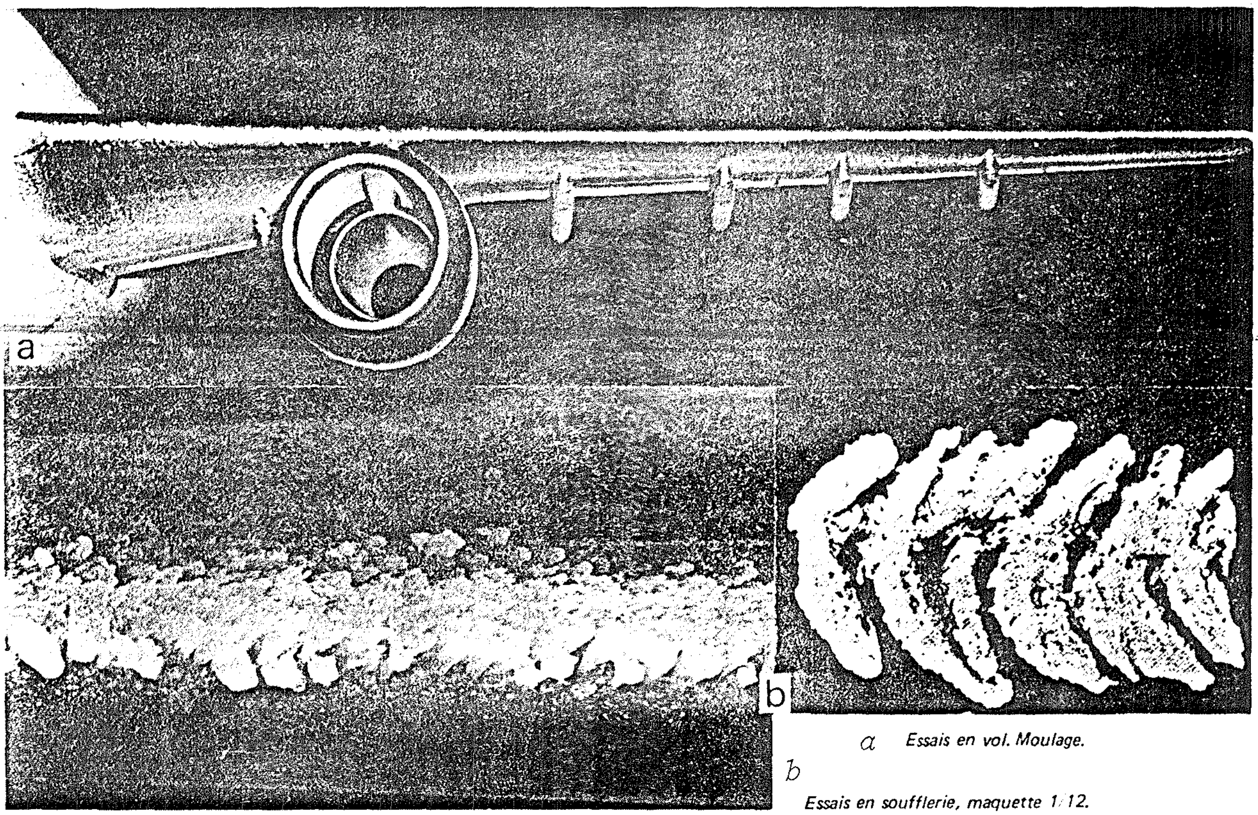

Fig. 8. Icing tests on the Airbus model at scale 1/12.
a) Test assembly; b) flight-wind tunnel comparison

Key: a. Flight test: cast.
b. Wind-tunnel test: 1:12 model

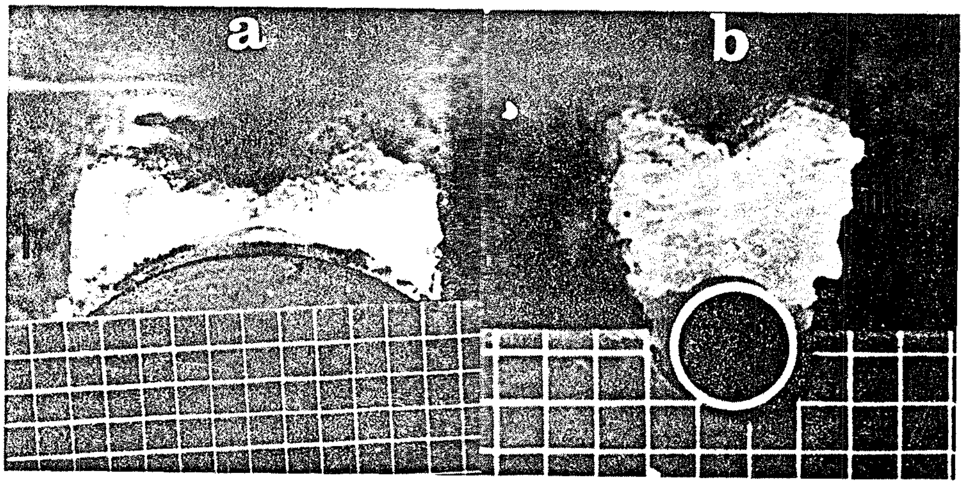

Fig. 9. Influence of scale, without similitude of the icing cloud, upon a cylinder. a) 150 mm diameter; b) 25 mm diameter.

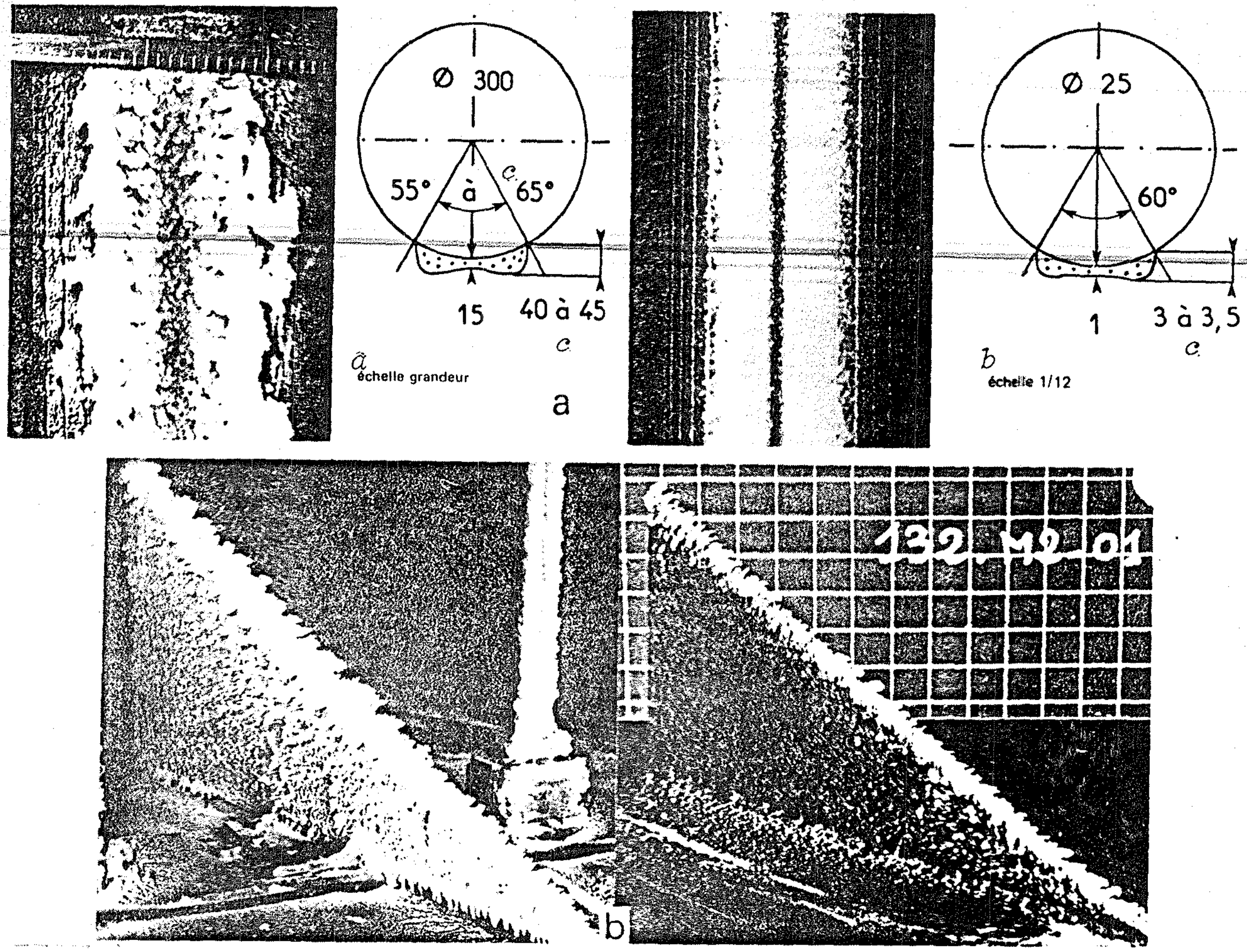

Fig. 10. Tests with similitude of icing cloud. a) on cylinders; b) on delta wings

Key: a. full-scale b. scale 1:12
c. à = to

Moreover, having available a facility for tests on model helicopter rotors, it was clear that the two systems should be combined to study icing of the rotors at a large range of speeds [4]. The additional condition for the similitude of centrifugal stresses on the deposited ice could be taken into account, and the tests were performed with the existing grill, suitably placed and restructured to cover the rotor (Fig. 11).

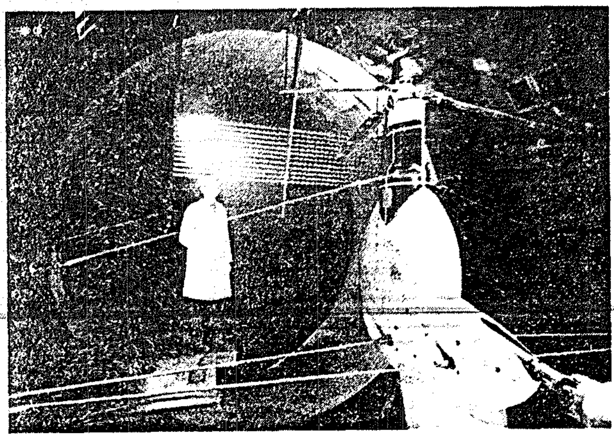

Fig. 11.

Test installation for icing on a helicopter rotor.

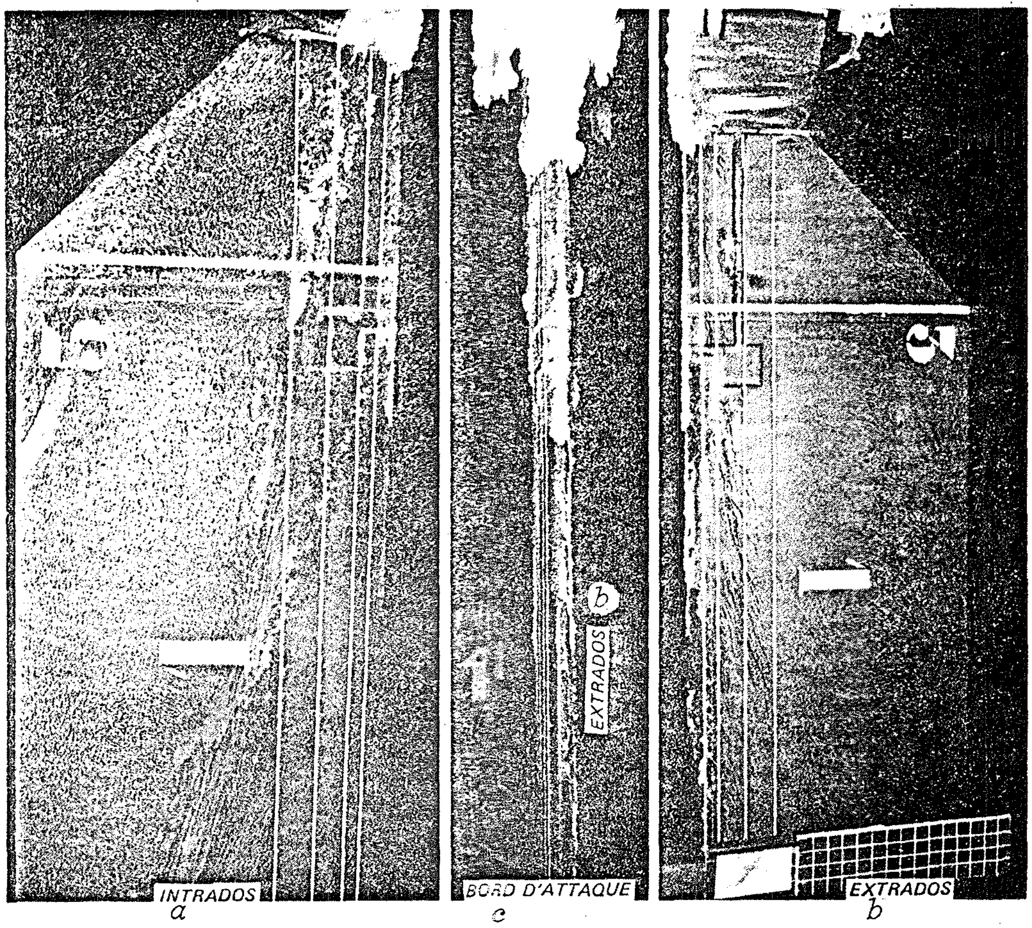

Fig. 12. Ice deposits on a rotor blade (photo obtained with stroboscope). Key: a. under surface b. upper surface c. leading edge

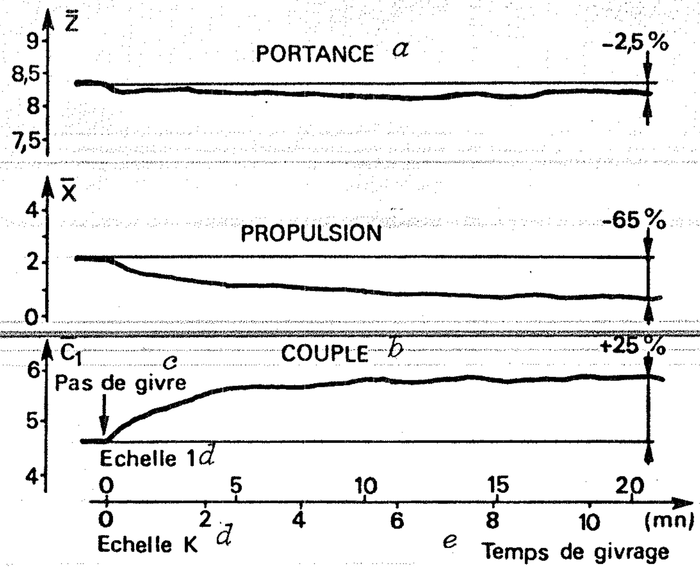

Fig. 13. Development of aerodynamic coefficients of a blade during icing.

Key: a. lift
b. torque
c. no ice
d. scale
e. icing time

During the test, the deposits were observed stroboscopically on a magnetoscope. Their evolution was thus followed step by step (Fig. 12).

The wind tunnel furthermore allows direct measurement of stresses on the rotor, thanks to a six-component balance. Their development during icing is typically analogous to that already found elsewhere in flight, particularly by Westland Helicopters. After a progressive alteration of the lift, propulsion and torque coefficients, these values stabilize corresponding to a cyclical development of deposition and disappearance of the ice on the blades, which has in fact been observed stroboscopically (Fig. 13).

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Gusts

Gust simulation is being prepared for the same wind tunnel, complementing a model support system with 4 degrees of freedom, for the study of flight mechanics close to ground level. Atmospheric gusts have a wave length of between 20 and 1000 m, but in the simulation the equivalent of 160 m will not be

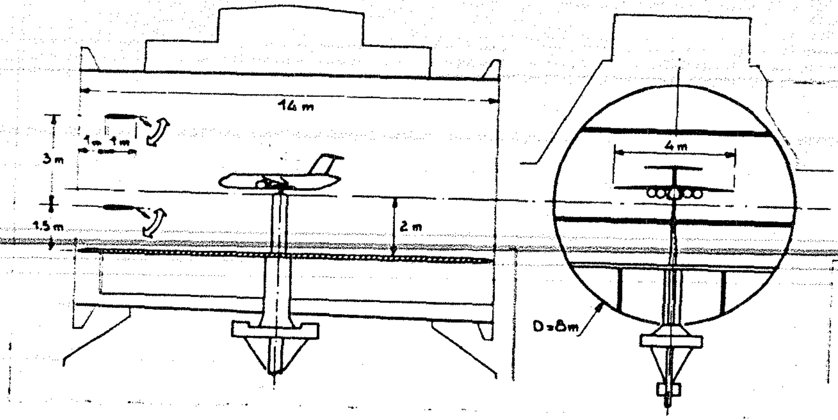

Fig. 14. Diagram of the gust generator for the S1-MA
Two solutions imagined for guiding the oscillating
jets: a) mechanical pulling; b) fluid deviation

exceeded -- i.e., 4 times the fuselage length of a transport plane. At 40 m/sec, the corresponding frequencies run from 0.25 to 2 Hz. Preliminary tests have been performed at 25 m/sec, in a wind tunnel representing Modane at a scale of 1:8; then the range is 12.5 to 100 Hz. The gust generator consists of two fixed profiles, with blowing onto the trailing edge perpendicular to the cord, directed outwards (Fig. 14). The system should make it possible, in its present form, to reach 6 degrees crest-to-crest, or a vertical speed variation of 4.2 m/sec for 40 m/sec of horizontal speed at Modane. This value is still lower than the maximums considered in the standards for this flight case, but this first stage, interesting in itself (Fig. 15), may be optimized later.

Conclusion

In conclusion, one can stress that the interest of aerospace manufacturers in the possibilities offered by these particular tests will justify the technical and

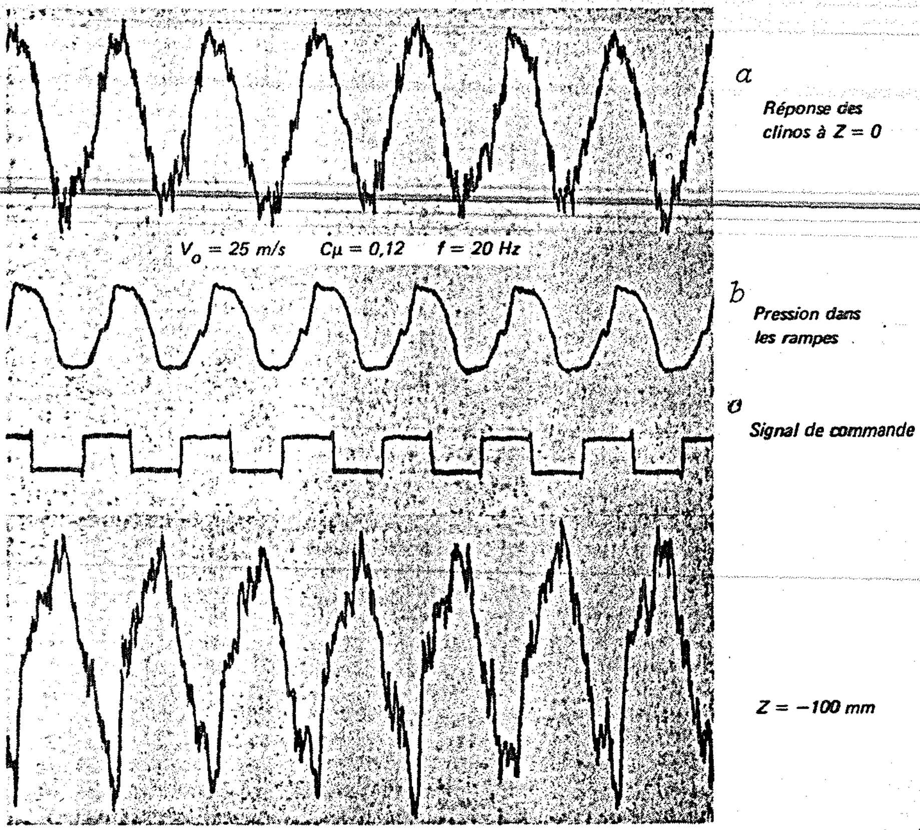

Fig. 15. Generation of periodic gusts by pressure intervals.

Key: a. response of "clinos" at Z = 0
b. pressure in the gradients
c. control signal

financial effort needed to extend their range of application to the wind tunnel. To do constructive work, one must consider not only the imperfections of these techniques relative to the ideal, which more over is inaccessible in practice, but also the interest and the abundance of the information they may furnish at a stage of development where other available means are still more limited, imperfect or conjectural.

Appendix 1

Characteristics of Icing Clouds

Meteorological statistics have allowed the official services to define the dimensional characteristics of icing clouds that may be encountered by aircraft in flight, as well as the technical conditions for granting the "icing" endorsement on navigability certificates.

In the demonstration test procedures for artificial icing, among which wind tunnel tests are included, two cases of icing are to be considered: /32-8

-- maximum continuous icing
-- maximum intermittent icing.

The atmospheric conditions corresponding to maximum continuous and intermittent icing are defined in the Table below for water droplets with a mean volume diameter of 20 μm:

Table AI: Maximum icing conditions

Température a atmosphérique (° C)	Quantité d'eau liquide (g/m³) b	
	Continu c	Intermittent
0	0,8	2,5
− 10	0,6	2,2
− 20	0,3	1,7
− 30	0,2	1,0
− 40	−	0,2

Key: a. atmospheric temperature (°C)
b. quantity of liquid water (g/m^3)
c. continuous

For continuous icing, the extent of the cloud is considered unlimited; however, for demonstration tests, it is considered equal to a 30-minute trajectory for cruising and holding pattern flight configurations, and the real flight time for climbing

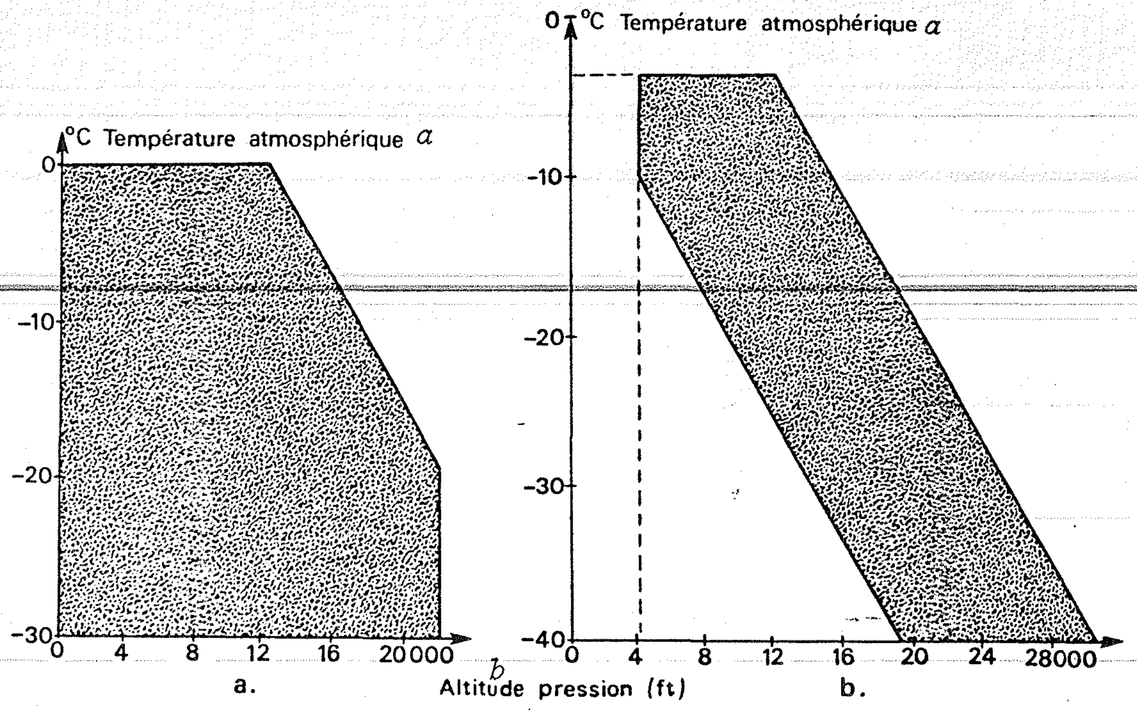

Fig. A1. Maximum icing ranges: a) continuous, b) intermittent
Key: a. atmospheric temperature b. pressure altitude

and descent flight configurations.

For intermittent icing, the extent of the cloud is 5 km; however, for demonstration tests, the corresponding cloud formations will consist of 5 km clouds separated either by areas of clear air or by maximum-continuous clouds with an overall duration as defined above.

The temperature and pressure altitude ranges where these types of clouds are encountered are defined in Figs. A1.

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